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THEORETICAL MODELING OF OCULAR TISSUE DAMAGE BY SHORT PULSE LASERS

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11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release;
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13. ABSTRACT (Maximum 200 words)

The effects of short pulsed lasers in ocular tissues involve both thermal and mechanical damage. In the past year of study we have examined the literature values for the threshold radiant exposure causing "minimal visible lesion". In particular, the threshold exposures for short pulses in the sub-100-ps regime were examined. Two possible mechanisms of mechanical damage in the retina were considered: (1) melanosomal disruption, and (2) shock front development.

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Date: May 27, 1994

Number: F49620-93-1-0298

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A. STATEMENT OF WORK

(1) MELANOSOMAL DISRUPTION

RATIONALE:

A hypothesis was proposed for a mechanism of laser-induced mechanical injury which predicts the roughly 10-fold drop in the threshold radiant exposure for "minimal visible lesion".

The postulated mechanism is "midcenter spall" of the melanosome caused by internal reflectance of the melanosomal pressure wave induced by a laser pulse below 100 ps.

1. The laser deposits energy in the melanosome.
2. The melanosome undergoes thermoelastic expansion.
3. A pressure wave begins to propagate out of the melanosome.
4. The impedance mismatch between the melanosome and surrounding retina internally reflects about 4% of the pressure wave as a negative tensile wave.
5. The tensile waves reflected from the boundaries of the melanosome superimpose near the melanosome interior causing maximal negative stress which elicits a process of nucleation, void growth, and fragmentation of the melanosome.
6. Subsequent injury to the whole retina may follow several paths:
   a. One hypothesis is that a spallation process similar to the melanosomal disruption may occur at mechanically mismatched boundaries throughout the retina.
   b. Another hypothesis is that the disrupted melanosome may leak toxic components which cause further injury to the retina.

PUBLICATIONS:

A conference paper on this hypothesis was published (copy sent to Dr. Kozumbo).
A journal paper is in preparation.

FUTURE WORK:

We continue to develop the PHASE I (or simplified) description of pressure wave propagation within and surrounding a melanosome. Our goal is to deliver this model as code written in ANSI Standard C to be made available to the other investigators working with Armstrong Labs (Brooks Air Force Base).

(2) SHOCK FRONT DEVELOPMENT

RATIONALE:

The high pressures induced in melanosomes by short pulsed lasers may induce pressure waves which undergo nonlinear propagation and develop into a shock front. Such a shock front would be capable of causing damage distant from the melanosomes, and may explain the more general disruption of the retina caused by sub-100-ps laser pulses.

The Principal Investigator visited Los Alamos National Laboratory to establish a collaborative link with Dick Scammon and Ron Dingus for the purpose of conducting computer simulations of shock wave formation in soft tissues such as the retina in response to pulsed laser exposure. This effort constitutes the first step toward a PHASE II (or complex) modeling of laser-induced mechanical effects in the eye.

Preliminary simulations were conducted using the CHARTD code which is a one-dimensional hydrodynamic model. The simulations suggested that the viscoelastic nature of soft tissue may not allow shock front development when only thermoelastic expansion has occured. Rather, shock front development appeared to require high-velocity mass ejection in order to impart sufficient momentum transfer to elicit "shocking up" of the laser-induced pressure wave. If this is true, then the hypothesis that injury occurs due to a shock front would become unlikely.

PUBLICATIONS:

We are preparing animated sequences of the shock front development based on the CHARTD simulations. Hopefully these animated sequences will be presented at the July 4-8 Gordon Conference on "Lasers in Medicine and Biology", where the PI is an invited speaker, so that the work can receive critical review.

FUTURE WORK:

The computer simulations will be further refined and studied. The laser parameter space of the simulations will be expanded to more fully specify the requirements for shock front development. Although the model is one-dimensional, it constitutes a worse-case scenario for shock front formation. A three-dimensional model of pressure wave propagation from a nearly spherical melanosome would be less likely to develop a shock front than the one-dimensional case being considered.

B. STATUS OF RESEARCH EFFORT

The status of the research effort is "ongoing". Details are listed under "Future Work" in the above "STATEMENT OF WORK".

C. CUMULATIVE CHRONOLOGICAL LIST OF WRITTEN PUBLICATIONS.

1. S. L. Jacques, A. A. Oraevsky, R. Thompson, B. S. Gerstman: "A working theory and experiments on photomechanical disruption of melanosomes to explain the threshold for minimal visible retinal lesions for sub-ns laser pulses." Soc. Photo-opt. Instrum. Engineer. 2134A, 1994. (paper and public presentation, Los Angeles, Jan, 1994)

2. S. L. Jacques: invited talk at the Gordon Conference on "Lasers in Medicine and Biology". (July 4-8, 1994, Kimball Union Academy, New Hampshire).

D. PROFESSIONAL PERSONNEL

1. Steven L. Jacques, Ph.D.
2. Lihong Wang, Ph.D.
3. Alexander A. Oraevsky, Ph.D.

E. INTERACTIONS

(i) Papers presented.

S. L. Jacques, A. A. Oraevsky, R. Thompson, B. S. Gerstman: "A working theory and experiments on photomechanical disruption of melanosomes to explain the threshold for minimal visible retinal lesions for sub-ns laser pulses." Soc. Photo-opt. Instrum. Engineer. 2134A, 1994.

(ii) Consultative and advisoryfunctions.

1. Collaborative interaction with Los Alamos National Lab (see section A.2 above). (Dick Scammon, Ron Dingus)

2. Collaborative interaction with Armstrong Laboratory, Brooks Air Force Base. (Randy Thompson) and one of their subcontractors (Bernard Gerstman, Florida International University). Several visits to Houston by Thompson and Gerstman have contributed to the collaborative study of mechanisms of melanosomal disruption.

F. NEW DISCOVERIES

A new hypothesis for the mechanisms of retinal injury by sub-100-ps laser pulses has been formulated (see section A.1 above).